CHAPTER 9

SEISMIC UPGRADING OF NONSTRUCTURAL ELEMENTS

9-1. Introduction

This chapter prescribes guidelines for evaluating seismic resistance of nonstructural elements in existing buildings that must remain intact or functional after a major seismic disturbance. The provisions of this chapter consist of a qualitative evaluation based on available pertinent design and installation documents and on-site inspection, and a detailed analytical evaluation using either a dynamic approach prescribed in the Seismic Design Guidelines (SDG), chapter 6, or a static approach prescribed in the Basic Design Manual (BDM), chapters 9 and 10. This chapter also discusses modes of damage to nonstructural elements and their anchorages and suggested strengthening measures for correcting seismic deficiencies identified in the evaluation of existing structures.

9-2. Acceptance criteria

The acceptance criteria for the seismic resistance, details of anchorages, and performance of existing nonstructural elements will be essentially as prescribed in the BDM and/or SDG. However, if existing elements or their anchorages do not conform to the above criteria, a tolerance of 15 percent overstress (i.e., 15 percent understrength) is acceptable if required seismic upgrading would be an excessively expensive and disruptive process.

9-3. General considerations

a. Elements to be considered. Nonstructural elements, which are generally categorized as architectural, mechanical, or electrical, include items that are housed in or on the building, as well as portions of the building that are not part of the structural system. Some nonstructural elements are classified as essential systems. Essential systems include all elements that are needed for the performance of emergency services or that may, by their failure, cause life hazard or impair the performance of services. These systems are outlined in SDG, paragraph 6-7 and table 6-3.

b. Vulnerability to seismic damage. Damage can occur to nonstructural elements from two basic types of motion: large story accelerations that cause elements to topple, fail the anchor supports, or cause damage; and large interstory displacements that will cause damage to elements rigidly attached to the adjacent floor slabs. In addition, the presence of rigid nonstructural elements can affect the performance characteristics of the structural system. For example, the inclusion of an unreinforced masonry wall, tightly fitted within a structural steel framing system, will greatly increase the stiffness of the structure, will increase the force level due to the shortened period, and will change the distribution pattern of forces to the structural elements. While the nonstructual elements can generate unexpected forces in the structural system, so does the structural system create unexpected forces in the nonstructural system. Furthermore, the failure of one element may ultimately cause the failure of another element or an entire system.

c. Reasons for seismic upgrading. There are generally four basic issues in the decision-making process to decide whether nonstructural elements are in need of upgrading and to what extent the upgrading is needed.

(1) *Functional loss.* Nonstructual damage may cause serious postearthquake disruption in essential services and productivity.

(2) *Life safety.* Nonstructural damage may injure people.

(3) *Economic loss.* Nonstructural damage may be costly.

(4) *Structural interaction.* Nonstructural elements may interact with structural components and may change the overall structural behavior, which can be beneficial or harmful to the structure.

9-4. Qualitative evaluation

Because of the great number of nonstructural elements and systems in existing buildings, a qualitative evaluation is made prior to a detailed quantitative evaluation to determine the general susceptibility to damage of the nonstructural elements and systems under investigation. The qualitative evaluation includes an assessment of conformance with minimum design and installation requirements, the need for detailed quantitative evaluation as described in paragraph 9-5, and the requirements for seismic upgrading. The following factors should be considered in the decision-making process:

a. Classification. This factor is based on the classification of nonstructural elements in accordance with function, life safety, and economic requirements. The following is an order of priority of importance:

(1) All nonstructural elements that are housed in an essential facility with special attention to

essential systems required for life safety and postearthquake operations.

(2) Essential systems housed in a high-risk facility.

(3) Essential systems housed in other buildings.

(4) All nonstructural elements that are not covered above.

b. Building and site characteristics. The vulnerability of nonstructural elements are dependent on the amplitude of ground motion (e.g., response spectra of EQ-I and EQ-II) and the dynamic response characteristics of the building (e.g., periods of vibration and mode shapes). Data from the structural evaluation of the building will aid in the evaluation of nonstructural elements.

(1) Flexible equipment is susceptible to damage when its period of vibration is in tune with the natural periods of the building.

(2) Elements attached to adjacent floors are more susceptible to damage when located in flexible buildings.

c. Seismic vulnerability. A qualitative evaluation requires judgment and experience on the part of the engineer in assessing seismic vulnerability of nonstructural elements. Possible modes of failure must be anticipated in order to identify the elements most susceptible to damage from earthquakes. Table 9-1 compiles a listing of types of damage that should be considered in the evaluation. This is not presented as an all inclusive listing, but is presented as a guideline on the basis of experience and observations by others.

d. Field inspection. Many of the installation details of nonstructural elements are often omitted from drawings because of common construction practices that have left many of these decisions to product manufacturers and installers. Therefore, it is important that design and installation details of nonstructural elements, especially essential elements, be investigated thoroughly during onsite field inspection. Furthermore, the observed existing conditions should be compared with idealized construction and strengthening practices, as recommended in paragraph 9-6. Any observed deviation from these suggested measures would downgrade the seismic resistance capacity of the elements under investigation, and a further evaluation and/or a remedial action should be taken.

e. Rapid analysis. A minimum of engineering calculations, on the basis of approximate element weights and earthquake response accelerations, may be required to supplement the qualitative evaluation procedure. The force and deformation criteria will be in accordance with the provisions of the BDM and/or SDG.

9-5. Detailed evaluation

The elements and their anchorages that have been identified in the qualitative evaluation procedure to be susceptible to damage will be subjected to a detailed evaluation. The nonstructural elements and their anchorages will be checked to resist forces and deformations caused by earthquake motions prescribed for buildings in this manual. The effect of nonstructural elements on the performance of the building will also be considered. Either a dynamic approach prescribed in SDG, chapter 6, or a static approach prescribed in BDM, chapters 9 and 10, may be used, except when authorized the dynamic approach will be used in the evaluation of essential systems.

9-6. Representative upgrading techniques

Since structural quality and anchorage of nonstructural elements in existing buildings vary greatly, it is not feasible to present methods of strengthening all such elements in detail, especially for mechanical and electrical elements where there are many different types and models. Such equipment is usually designed and installed by manufacturers without consideration of seismic resistance. Care and engineering judgment should be exercised for determining the best feasible methods of upgrading. Economic feasibility must be weighted against seismic risk in strengthening nonstructural elements, as should be done for buildings as a whole. For example, loss of files, computer facilities, or communication systems in a medical facility can shut down the system. Some general upgrading measures are outlined in this paragraph.

a. Architectural elements.

(1) *Exterior walls, parapets, appendages, veneers, etc.*

(a) Reduce height of parapet or brace to the roof structural system, as necessary.

(b) Anchor appendages, veneers, and other potential falling objects or replace their anchorages, as needed.

(c) Refer to BDM, figure 9-2, for design of exterior precast elements.

(2) *Interior walls and partitions.*

(a) Remove clay-tile partitions.

(b) Provide lateral bracing for partitions.

(c) Separate partitions from structural elements with sufficient joints coordinated with anticipated interstory drifts.

(d) Refer to BDM, figure 9-1, for typical details of interior walls and partitions.

(3) *Ceilings: Suspended system and surfaced applied system.*

Table 9-1. Guidelines for evaluating seismic performance of selected nonstructural elements. (Sheet 1 of 4)

System/Element	Potential Types of Damage
Architectural	
Appendages:	
Exterior P/C panels	Failure of connections due to prying action; bolts pull out.
Parapets	Cracks due to cantilever action.
Ornaments, veneers	Failure of anchorage-
Partitions:	
Permanent-masonry, tile, metal stud, gypsum board, plaster	Damage occurs in the anchorage to the supporting structure and in the cracking of brittle surfaces.
Demountable-metal, wood, metal/glass	Separation at top/bottom channels, overturning and compression failure, glass cracking.
Ceiling:	
Exposed tee bars and luminous systems	Tees deform or pulled away from the wall support; breakage of hangers.
Concealed spline system	Damage occurs at perimeter walls where supports bend and tiles tear and fall.
Gypsum board with tiles, plaster	Gypsum boards drop and loosen tiles at perimeter walls.
Wood joists with nail or tiles	Most earthquake resistant of all ceiling types.
Lighting Fixtures:	
Recessed	Separation of fixtures due to racking of suspended ceilings.
Surface mounted	Generally undamaged by earthquakes.

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Table 9-1. Guidelines for evaluating seismic performance of selected nonstructural elements. (Sheet 2 of 4)

System/Element	Potential Types of Damage
Pendant	Very susceptible to damage; failures at ceiling connections, in swivel joints, at fixture housings, in supporting stems or chains. Damage to suspended ceiling.
Building Contents:	
Shelving, cabinets, storage racks	Overturning, dislodging of stored items.
Computer equipment	Top-heavy tape transports fall over; impact damage caused by equipment hitting walls or other equipment.
2. Mechanical	
Rigidly Mounted Equipment:	
Equipment	Equipment without anchors cause secondary damage on connected pipes and electrical service connections.
Tanks	Unanchored tanks tip over, legs and support brackets collapse; secondary damage to connecting piping.
Equipment with Vibration Isolators:	More susceptible to damage than fixed mounted equipment; failure of isolators causes equipment to fall and damage to connecting piping and electrical service connections.
Piping:	Failures at elbows and bents due to excessive movement; screwed fittings are more vulnerable to damage than welded or brazed fittings; failures at building seismic joints due to differential movements; failure of hanger assembly.

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Table 9-1. Guidelines for evaluating seismic performance of selected nonstructural elements. (Sheet 3 of 4)

System/Element	Potential Types of Damage
Ducts, Diffusers, etc.:	Long runs of large ducts fail as a result of excessive motion by the earthquake; large diffusers drop from ceilings where they lack proper Support.
3. Other Essential Systems	
Elevators: Traction	
Counterweight guide systems	Counterweights derail, allowing them to swing.
Cabs guide systems	Out of alignment.
Motor generator sets	Thrown off their unanchored isolation mounts.
Control panels	Topple over where not anchored to structural frame.
Control relays	Damaged when unlatched and hinged panels thrown open.
Elevators: Hydraulic	No specific experience on observed damage.
Emergency Power System:	
Transformers	Inadequately secured transformers fall from pedestals, causing major damage to bushings, radiators, internal parts, and interconnecting bus; pole transformers are more vulnerable to damage than pedestal—mounted.
Switchgears	Notion of unsecured switchgears damage connections to the equipment.
Motor and generators	Vibration isolators shear off; damage power, fuel, and cooling line connections.

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Table 9-1. Guidelines for evaluating seismic performance of selected nonstructural elements. (Sheet 4 of 4)

System/Element	Potential Types of Damage
Battery racks	Generally remain in place when strapped to walls.
Panel boards	Overturning of unsecured tall units; rigid conduit failure due to support failure
Fuel storage tanks	Fracture of pipe connections due to excessive movement of unanchored support.
Fire Protection System:	
Sprinkler and stand pipes	Only minor damage has been observed.
Pumps and tanks	Fracture of pipe connections due to excessive movement of unanchored support.
Steel stairs	Yielding of welded connections.
Concrete stairs	Shear cracking if tied to the structure.
Doors and frames	Doors deform and jam; frames warp.
Corridors	Corridors blocked with debris.
Hazardous Materials:	
Storage tanks, bottles, cylinders, and pipes containing hazardous toxic materials	Expose chemicals due to rupture of containers; damage caused by excessive movement or failure of adjacent elements.
Communications:	
Intercom/PA system, telephone equipment, and switchboards	Loss of communications due to broken wires.

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(a) Brace ceiling grid at regular intervals against lateral and vertical movements.

(b) Fasten cross runners to the main runners with locking clips to prevent cross tees from pulling or twisting out of the main runners.

(c) Brace ductwork and piping systems in the ceiling space against lateral and vertical movements.

(d) Positively connect all elements together.

(e) Reinforce gypsum board ceiling at nail points, using large-head nails or steel nailing strip.

(f) Refer to BDM, figure 9-3, for recommended suspended ceiling system.

(4) *Lighting fixtures: Recessed fixtures, surface-mounted fixtures, and pendant fixtures.*

(a) Secure recessed fixtures directly to the main runners of the ceiling system.

(b) Provide recessed fixtures with independent secondary supports attached to the fixture housing and the building structures.

(c) Attach surface-mounted fixtures directly to the building structure and suspended ceiling system using positive locking devices.

(d) Separate pendant fixtures sufficiently so that sway arcs do not intersect.

(e) Provide sway bracing if swinging clearance of chain-hung fixture is not adequate.

(f) Refer to BDM, paragraph 10-6, for the design requirements of lighting fixtures and supports.

(5) *Building contents:* Shelving, storage racks, filing cabinets, computer equipment, etc.

(a) Anchor all storage racks at base and laterally brace at top or attach to walls.

(b) Provide safety bars for open shelving where practical.

(c) Brace computer floors and provide drop-in panels detailed to prevent displacement during an earthquake.

b. Mechanical systems:

(1) *Mechanical equipment:*

(a) Anchor all floor-mounted equipment to the structural slab.

(b) Provide isolation restraints for all hung equipment.

(c) Remove vibration isolators and bolt equipment to floor slab or add snubbers to limit excessive movement.

(2) *Distribution system:* Pipes, ducts, and conduit.

(a) Provide sway bracing in both longitudinal and transverse directions on all pipes 2½ inches or larger, based on intervals recommended in BDM, figures 10-4 to 10-7. Also refer to BDM, figure 10-8, for acceptable details of sway bracing.

(b) Provide flexible joints where pipes enter building, where rigidly supported pipes connect to equipment with vibration isolation, and where needed to accommodate large interstory drifts for large pipe risers rigidly mounted between floors. Refer to seismic details in BDM, figure 10-9.

(c) Provide pipe sleeves through walls or floors large enough to allow for relative movements.

(d) Provide sway bracing in both longitudinal and transverse directions on all ducts with a perimeter greater than 120 inches and for all ducts in boiler and equipment rooms.

(e) Diffusers, registers, and grillers should be positively attached to the ductwork.

(f) Positively tie flexible ducts to the ceiling, wall, or floor system.

c. Essential systems that are not covered above.

(1) *Elevators: Traction and hydraulic types.*

(a) Install additional rail support brackets and brace spreader beams (counterweight).

(b) Install safety shoes on roller guide.

(c) Strengthen the car guide rails on long spans by installing spacers between the back-to-back rails at midpoints between the spreader beams.

(d) Protect traveling cables to prevent them from being twisted and snarled or from jumping out of their sheaves or guides.

(e) Design more rigid structural frames around hoistways and door frames that can accommodate the anticipated interstory drifts.

(f) Anchor motor generators and control cabinets or provide restraints on vibration isolators under generators to prevent excessive movement.

(g) Install emergency stop gear.

(h) Refer to BDM, figure 10-13, for details of traction-type elevator.

(2) *Emergency power system.*

(a) Anchor or restrain transformers, switchgear, and control panels.

(b) Bolt generator directly to foundation.

(c) Brace cooling tower or install an auxiliary cooling system such as generator radiator system at grade level.

(d) Anchor fuel storage tank and install flex loops in fuel lines between the tank and the building and at the connection to the generator.

(e) Strap all batteries on racks; anchor and brace storage racks.

(3) *Fire protection system.*

(a) Install mounting brackets for hung and free-standing fire extinguishers.

(b) Brace standpipes.

(c) Brace the sprinkler system piping in accordance with NFPA No. 13 (refer to BDM, paragraph 10-7); fire pumps should be governed by NFPA No. 20.

(d) Provide slip joints at the top or bottom of each flight of stairs.

(e) Ensure that exitways will not become blocked after an earthquake.

(4) *Protection against hazardous materials.*

(a) Install seismic-activated shut-off valves at appropriate locations on supply lines for natural gas and other hazardous materials.

(b) Brace fuel lines, bottles of laboratory chemicals, lead storage safes for radioactive materials, liquid oxygen storage tanks, and similar containers and protect them from damage caused by movement or failure of adjacent elements.

(5) *Communications.*

(a) Secure and anchor emergency comunication equipment or relocate in a nonvulnerable portion of the facility, preferably the lower levels.

(b) Provide alternate internal and external communication systems.